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METHOD AND APPARATUS FOR PREPARING
FIBRINOGEN ADHESIVE FROM WHOLE BLOOD

10 Technical Field

The invention is related to medical and veterinary technology and procedures. More specifically, it concerns a convenient method for preparation of a fibrinogen adhesive directly from withdrawn blood.

15 Background Art

The need for a suitable tissue adhesive for use in surgical procedures in human and animal medicine is well understood, and has been for nearly a century.

20 Various substances have been tried, including completely synthetic materials such as cyanoacrylate. Because, however, the ability of the natural material fibrin to behave as an adhesive is known, fibrin powders were used for this purpose early in the development of this technology.

25 It has also long been recognized that the in situ formation of fibrin from fibrinogen is a preferable approach. In a relatively recent article, Staindl, O., in Ann Otol (1979) 88:413-418, described the use of a combination of three separately prepared substances, human fibrinogen cryoprecipitate, thrombin in the presence of calcium ion, and Factor XIII concentrate, to obtain a glue that was applied in skin graft applications, myringoplasty, repair of dural defects, hemeostatis after
35 tonsillectomy, and tracheoplasty. Around this time, Immuno-AG, Vienna, Austria, began producing and com-

mercializing a two-component "fibrin seal" system, wherein one component contains highly concentrated human fibrinogen, Factor XIII, and other human plasma proteins, prepared from pooled blood, and the other component supplies thrombin and calcium ion. The two components are added together in the presence of a fibrinolysis inhibitor. After application, the processes of coagulation and fibrin cross-linking occur. Eventually, the seal may lyse in the process of healing of the wound or trauma which accompanies the reconstruction of the tissue. Redl, H., et al., "Biomaterials 1980," Winter, G.D., et al., eds. (1982), John Wiley & Sons, Ltd., at page 669-675, describe the development of an applicator device for this system which mixes and applies the two components of the system simultaneously.

This two-component system has been marketed over the last ten years under the trade name Tissucol[®] or Tisseel[®], and a number of publications have appeared describing the use of this preparation in surgical procedures. See, for example, Seelich, T., J Head and Neck Pathol (1982) 3:65-69; O'Connor, A.F., et al., Otolaryngol Head Neck Surg (1982) 90:347-348; Marquet, J., J Head and Neck Pathol (1982) 3:71-72; Thorson, G.K., et al., J Surg Oncol (1983) 24:221-223. McCarthy, P.M., et al., Mayo Clin Pros (1987) 62:317-319, reported the addition of barium ion to this fibrin glue system in the treatment of a bleeding duodenal sinus in order to facilitate follow-up surveillance. See also Portman, M., J Head and Neck Pathol (1982) 3:96; Panis, R., ibid., 94-95.

It has been recognized, of course, that the use of the commercial product, which is prepared from pooled human blood, poses at least a theoretical risk of contamination by disease-producing organisms, especially viruses. The earlier concerns were directed to transmission of hepatitis B, but more recently the focus has

shifted to concern about inadvertent transfer of the AIDS virus. Therefore, attention has been given to methods to isolate an autologous counterpart of the fibrinogen-containing component in the Tissucol® system in a practical manner for use in surgery. For example, Siedentop, K.H., et al., Laryngoscope (1985) 95:1074-1076, describes a number of approaches to the precipitation of fibrinogen from plasma in the context of the proposed use of this material as the fibrinogen-furnishing component of a fibrin glue. Four methods were suggested: Precipitation with ethanol, use of unfractionated plasma, cryoprecipitation, and precipitation with ammonium sulfate. The first three methods were considered by the authors to be unsatisfactory; the fourth, which was the method described by Harker, L.A., et al., New Eng J Med (1972) 287:999-1005, was considered to have some promise. Epstein, G.H., et al., Anal Otol Rhinol and Laryngol (1986) 95:40-45, suggest the use of a fibrinogen preparation from autologous plasma obtained using polyethylene glycol precipitation. These authors adapted the method of Masri, M.A., et al., Thromb Hemeostas (1983) 49:116-119, which involved incubation of the harvested plasma with barium sulfate and magnesium sulfate in order to remove thrombin (and thus prevent premature fibrin formation) followed by treatment of the supernatant from the resulting precipitation with a 30% solution of polyethylene glycol (PEG) of MW approximately 1000. This purified fraction was then mixed with thrombin containing calcium ion in order to form the glue. The isolation process required approximately two-three hours, but the PEG-precipitated fraction could be stored for as much as several weeks, and therefore the preparation could be made in advance of surgery. Autologous fibrinogen preparations obtained following this procedure were shown to be adhesive with implant materials by Feldman, M.C., et al., Arch Otolaryngol--Head and Neck Surg (1988) 114:182-185;

additional applications of this approach to other surgical indications were also reported by Feldman, M.C., et al., Arch Ophthalmol (1987) 105:963-967; Feldman, M.C., et al., M J Otolary (1988) 9:302-305; Silberstein, L.E., et al.,
5 Transfusion (1988) 28:319-321.

In addition, the material prepared as described by Epstein et al., by barium sulfate/magnesium sulfate precipitation followed by treatment of the supernatant with polyethylene glycol, was characterized to as to its
10 components by Weisman, R.A., et al., Laryngoscope (1987) 97:1186-1190. The product was found to contain about 13-50 mg/ml of fibrinogen when the material precipitated from 50 ml blood was brought to a volume of 1 ml, wherein this concentration varies with the concentration of PEG. The
15 percent of total protein attributable to fibrinogen ranged from 42-92 percent; the lower the PEG concentration, the higher the percentage of fibrinogen. The concentrations of kallikrein and pre-kallikrein were shown to be reduced to 1-2% of their levels in plasma in the presence of 10%
20 PEG, and Factor XIII activity was shown to be present.

A system for preparing autologous tissue adhesive was also described by Weis-Fogh in PCT Application _____, which discloses a reasonably complex system based on ethanol precipitation:

25 General methods for preparing plasma adhesives have also been described in a series of related U.S. patents by Schwarz et al. assigned to Immuno-AG: U.S. 4,414,976; 4,298,598; 4,362,567; and 4,377,572. These methods involve cryoprecipitation of the adhesive material
30 from plasma and various work-up procedures to obtain a mixture of defined composition. In addition, U.S. Patent 4,427,650 to Stroetmann describes a preparation method involving the formation of a cryoprecipitate.

Very early studies on blood fibrinogen, un-
35 related to the preparation of adhesive compositions, experimented with the use of glycine as a precipitant. A

5 Moesson, M.W., et al., Biochemistry (1966) 5:2829-2835,
recognized that fibrinogen can be directly precipitated in
this manner, but did not assess the suitability of the
precipitated material to behave as a controlled adhesive.

The present invention, by providing a surprisingly simple method and apparatus for the preparation of autologous adhesive, permits the autologous composition to be prepared in the operating room and administered at the time of preparation.

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system--the fibrinogen preparation as one component and a thrombin/ Ca^{+2} composition as another. The Tissucol system uses a double-syringe arrangement wherein the two components are mixed in the injector immediately prior to dispensing. No means to remove debris or excess adhesive from the site of application is provided, and the potential for premature adhesion also exists. The present invention also provides an applicator with a premix immediately upstream of the application outlet means and a means to apply suction at the outlet to maintain the application area in condition for successful adhesion.

Disclosure of the Invention

The invention provides effective means to prepare and administer autologous plasma-derived adhesive during the course of a surgical procedure. The method of the invention can also be used to prepare the adhesive under less constrained conditions, but the simplicity and ease with which the invention method results in the desired adhesive makes it adaptable to this important use.

The invention process provides the desired adhesive composition in a one-step treatment directly applicable to separated plasma using a recognized, nontoxic precipitant, such as suitable concentrations of amino acids, but preferably a nontoxic polymer such as polyvinyl alcohol (PVA) or polyethylene glycol (PEG). The fraction precipitated by these pharmaceutically acceptable reagents results in a high concentration of fibrinogen in the precipitate, along with other factors necessary for fibrin formation, as well as permitting the use of a simple, disposable apparatus to carry out the manipulations.

Thus, in one aspect, the invention is directed to a process for preparing a fibrinogen adhesive composition from whole blood, which process comprises directly contacting plasma with an amount of polyethylene glycol of molecular weight 200-8000, or other precipitant selected

from the group consisting of amino acids and nontoxic hydrophilic polymers, which is effective to precipitate the fibrinogen-containing fraction. Then the precipitated fibrinogen fraction is recovered for use, either by
5 mechanical disruption of the precipitate or pellet or by suspension in an aqueous medium.

In another aspect, the invention is directed to the fibrinogen-containing preparation obtained by the method of the invention.

10 In still another aspect, the invention is directed to an apparatus for preparing the fibrinogen composition consisting essentially of a device with dual separation chambers with a means for fluid communication between the chambers.

15 In still another aspect, the invention is directed to an applicator for injecting this or any other two-component system into a human or other animal subject which provides for simultaneous application of suction at the outlet for the components, and to a method to
20 administer the fibrinogen composition using this apparatus.

Brief Description of the Drawings

FIG. 1 is a perspective view of one embodiment
25 of the apparatus of the invention for preparing the plasma-derived adhesive.

FIG. 2 is an alternative embodiment of the isolation apparatus of the invention.

FIG. 3 is an additional alternative embodiment
30 of the isolation apparatus of the invention.

FIG. 4 is a longitudinal sectional view of an apparatus for administering a two-component composition to an animal subject.

FIG. 5 is a perspective view of the apparatus of
35 FIG. 3.

FIGS. 6A and 6B are perspective views of the mixing head of the apparatus of FIGS. 4 and 5.

FIG. 7 is a perspective view of the filler tray and reservoir tip of the apparatus of FIGS. 4 and 5.

Modes of Carrying Out the Invention

The Adhesive Composition

The adhesive composition of the invention contains substantial amounts of fibrinogen and sufficient Factor XIII to effect fibrin formation and cross-linking in the presence of added thrombin and calcium ion. Thus, as used herein, "fibrinogen adhesive composition" refers to a fraction of blood plasma which contains substantial amounts of fibrinogen and sufficient amounts of other factors required for fibrin formation that, when combined with a preparation of thrombin and calcium ion, fibrin formation and cross-linking takes place conferring on the composition the properties of a tissue adhesive.

It is believed that the formation of the adhesive occurs through the conversion of fibrinogen into fibrin monomers, which conversion is mediated by thrombin; these monomers aggregate and form a gel. Thrombin also catalyzes the transformation of Factor XIII to Factor XIII* which is activated in the presence of calcium ions to Factor XIIIa. Factor XIIIa cross-links the fibrin monomers of the gel aggregation into a polymeric state. The polymeric material adheres to tissue or bone, and continued cross-linking can occur as Factor XIIIa also cross-links fibronectin.

Therefore, the necessary components of the fibrinogen adhesive composition are fibrinogen itself and Factor XIII. Other components may also be present or may be added to modify and improve the effect of the adhesive. For example, a fibrinolysis inhibitor, such as aprotinin or aminocaproic acid can also be added. In the composi-

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2-6 mg/ml concentration in plasma or whole blood. This is a range comparable to the commercially available Tisseel composition which contains 70-110 mg/ml. Also, like the commercial Tisseel composition, the fibrinogen adhesives of the present invention contain sufficient Factor XIII to provide cross-linking of the fibrin obtained. There may also be present varying amounts of plasma components which are not absolutely necessary for fibrin formation but may be helpful, such as, e.g., Factor VIII, prostaglandins, and platelets.

In general, the process begins with the withdrawal of whole blood from an autologous, or other, or multiple donors in the presence of an anticoagulant, and separation of plasma from the red blood cell fraction. Typical anticoagulants include heparin and sodium citrate; others generally known in the art may also be used. If sodium citrate is used, it is generally supplied as a buffer at physiological pH with citrate ion present at 3-5%. The sodium salt is preferred. The range of means to prepare citrate and other anticoagulants suitable for primary separation of blood into red blood cells and plasma is well understood in the art. Typically, the separation can be effected by centrifugation; a suitable protocol involves spinning at about 2000-5000 g for about 5-10 minutes.

In the method of the invention, after the plasma is separated from the red blood cells, it is treated directly, at ambient temperature, without prior treatment to remove thrombin, with a physiologically acceptable nontoxic precipitant. The precipitants of the invention include the natural amino acids and nontoxic polymers, especially polyvinyl alcohol and, most preferably, polyethylene glycol. Preferred amino acids are small neutral amino acids such as glycine, serine and alanine, most preferably glycine. Most preferred among the polymer precipitants is polyethylene glycol in a molecular range

of 200-8000 supplied as a concentrated solution. The precipitant is preferably supplied as a concentrated solution which, when mixed with plasma, will yield a concentration effective in precipitating the adhesive composition. Optimal concentration of the precipitant can readily be determined by routine experimentation; simple in vitro assays for fibrin formation, such as those described by Epstein, G.H., et al., Annals Otol Rhinol and Laryngol (1985) 287:999-1005, can be used, and fibrinogen content measured as described.

The concentrated solution or, in some instances, undiluted precipitant is added to the plasma in an amount effective to precipitate the fibrinogen adhesive composition of the invention. If PEG is used, the final concentration of PEG depends on the concentration of plasma in the precipitating solution and on the molecular weight of the PEG. A suitable and typical set of parameters utilizes an approximately 60% solution of PEG of molecular weight 1000 in saline at pH 7.4, and the plasma is added in sufficient volume (typically 10% w/v of precipitant solution/final volume) to obtain a resulting concentration of 8-15% w/v PEG in the volume of the final mixture. The plasma itself is, therefore, only slightly diluted. The precipitation takes place at room temperature and is complete essentially instantaneously, although generally it is advantageous to cure the precipitate for 5-10 min.

The precipitate containing the fibrinogen adhesive is then recovered, typically by centrifugation. The pellet may be recovered by mechanical disruption or resuspended in normal saline for use at a concentration of about 50 mg/ml-80 mg/ml of fibrinogen. Typically from about 60 cc of whole blood a fibrinogen adhesive composition which would contain 30-50 mg fibrinogen when resuspended to 1.5 ml is obtained.

The use of the amino acids and biocompatible polymers as precipitant has considerable advantage over the prior art use of ethanol and cryoprecipitation. The resulting concentration of fibrinogen is markedly higher, and the precipitants are recognized material safe for internal use. For example, PEG has been used as a lubricant or conditioner in ointments and in pharmaceutical and cosmetic preparations, including injectables. It is a water-soluble, nonvolatile material of no known clinical toxicity. The amino acids are, of course, nontoxic metabolites and are common components of pharmaceutical compositions.

Because of the benign nature of the precipitant, the remaining supernatant plasma fraction, which contains platelets and white blood cells, can be reused for other purposes; similarly, the red blood cells removed could, if desired, be returned to the patient.

Isolation apparatus

The process of the invention can be conducted using standard laboratory and medical equipment. For example, the blood may simply be withdrawn into a syringe containing anticoagulant and emptied into a centrifuge tube for separation. The supernatant plasma can then be removed by syringe containing the precipitant or can be pipetted into a separate vessel and the precipitant added. The suspension can then be centrifuged using standard equipment and the precipitated material disrupted or resuspended by addition of saline after removal of the supernatant.

It is evident, however, that the use of standard equipment adds complexity to the process and imposes requirements for sterilization of the various pieces of apparatus and maintenance of integrity of the sample. The invention apparatus provides a simple design which eliminates these complexities and streamlines the process.

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The invention apparatus contains two chambers, both of which can be used directly in a laboratory or medical centrifuge. The first chamber is designed to effect the separation of plasma and red blood cells; the second chamber provides a method to separate the fibrinogen adhesive composition from the supernatant plasma fraction. Because a means of fluid communication is provided between the first and second chamber, the plasma obtained in the first chamber can be made the subject of fibrinogen adhesive separation in the second, and the supernatant from the precipitate can be returned to the first chamber. The first chamber generally contains an effective amount of anticoagulant; the second chamber contains an effective amount of precipitant such as polyethylene glycol solution to effect precipitation of the fibrinogen adhesive. The apparatus, then, comprises a first and second chamber, a means of fluid communication between the first and second chambers and a means to interrupt this communication, wherein the first chamber contains anticoagulant and the second chamber contains the precipitant and permits the removal of the precipitate.

One convenient embodiment of the apparatus of the invention is shown in FIG. 1. In this embodiment, the apparatus consists of two especially adapted syringe bodies 10 and 11 interconnected by a supported tube 12. The tube is provided with a valve 13 which is capable of turning on and off the flow of fluid between chambers 10 and 11. Both of the chambers are fitted onto the frame and locked onto a tube having a T-joint at 10t and 11t. Both syringe cylinders are provided with a modified plunger 10p and 11p which may be withdrawn by a pulling means such as a plastic cord 10c and 11c causing the withdrawal of the plunger to a position flush with the ends of the cylinders where the top of the plunger is sealed by a flange (10f and 11f) when withdrawn to a fully extended position. This permits the syringe bodies to be used as centrifuge

In use, the plasma separation chamber 10 is fitted with a needle 10n which is inserted into the subject for withdrawal of blood. The valve 13 is closed during this step, thus preventing the formation of a vacuum in the connecting tube 12 and confining the flow of blood to the chamber 10 when the plunger 10p is withdrawn by pulling the cord 10c. The size of the plunger is adjusted to permit withdrawal of a predetermined amount of blood, typically 60 cc. The chamber 10 is previously supplied with sufficient citrate buffer to obtain a concentration of about 4% citrate ion when the predetermined amount of blood is withdrawn.

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After centrifugation, the valve 13 is opened and the plunger 11p is withdrawn and sealed at flange 11f, thus transferring the plasma into chamber 11. Chamber 11 is presupplied with an approximately 60% PEG solution of molecular weight 1000, or a comparable concentration of an alternate molecular weight sufficient to effect precipitation of the fibrinogen adhesive. The motion of the plungers is stopped when the red blood cells reach the upper portion of the chamber 10. The valve 13 is then closed.

If desired, the red blood cells remaining in chamber 10 can be withdrawn or expelled and returned to the patient.

The apparatus is then agitated, if necessary, to intermix the PEG with the plasma. Outlet 11o remains sealed. The chamber 11 is then centrifuged either within the device or after removal therefrom to separate the precipitate from the supernatant plasma. The apparatus is, of course, inverted from the position shown in FIG. 1. After about 15-20 minutes at 6000-10,000 g sufficient separation of precipitate has occurred. The chamber 11 is replaced in the apparatus if it has been removed, and the valve 13 again opened while the outlet 11o remains sealed. The supernatant is then withdrawn into chamber 10 by withdrawal of plunger 10p (10o remains closed) until the fibrinogen precipitate begins to enter the connecting tube 12; valve 13 is then closed.

The fibrinogen adhesive is removed for use from chamber 11 by further reinsertion of the plunger 11p, or preferably by withdrawal into the syringe attached at the outlet 11o. If desired, the fibrinogen adhesive can be diluted in saline and the composition quantitatively removed from chamber 11 by washing.

It should be noted that chamber 10 now contains all blood components except the fibrinogen adhesive composition and contains as added components only anticoagulant and the clearly nontoxic PEG. Therefore,

FIG. 2 shows an alternative embodiment of the apparatus of the invention which dispenses with the need for the frame 14. This apparatus consists essentially of two syringes with detachable plungers and a Luer-locked connector. This embodiment has the advantage of utilizing standard medical equipment but the disadvantage of utilization of several separate parts.

10 In the apparatus of FIG. 2, the blood separation
syringe 20, is fitted with a needle for the withdrawal of
blood. Again, chamber 20 is supplied with a premeasured
quantity of citrate which, when mixed with the withdrawn
15 ion. When the plunger is retracted and chamber 20
contains whole blood, the needle and the extended portion
of the plunger are detached to permit the syringe body and
sealed end to be placed in a centrifuge, with the Luer
lock outlet 20o sealed. Suitable syringes with plungers
20 which can be detached and the body sealed for
centrifugation of the syringe body are available
commercially. The syringe barrel 20 is then centrifuged
as described above, and Luer lock at 20o is engaged by the
interconnecting tube 24, and the plunger is replaced.
25 With the syringe in the inverted position, the
interconnector 24 is attached to a second similarly
constructed syringe 21 at Luer lock 21o. Syringe 21
contains a premeasured quantity of PEG. Plasma is
transferred from chamber 20 to chamber 21 through
30 retraction of the plunger 21p which causes effective
reinsertion of plunger 20p. When red blood cells begin to
enter the interconnector, an event which is readily
observable, the interconnector 24 is detached from chamber
21 and the mixture of plasma and PEG in chamber 21
35 agitated if necessary. Syringe 21 is then prepared for
centrifugation by removal of the extended portion of the

plunger and sealing of the body of the syringe, and closure at 21o, and the fibrinogen adhesive and plasma are separated under the centrifugation conditions described above. The interconnector 24 and plunger 21p are then put
5 back in place and the plasma supernatant withdrawn into chamber 20 by retraction of plunger 20p. When fibrinogen adhesive precipitate begins to enter the interconnector, the interconnector is detached and the fibrinogen adhesive expelled into diluent, or diluent is withdrawn into
10 chamber 21 through 21o.

In either case, the resuspended fibrinogen adhesive is placed in a suitable applicator for use.

FIG. 3 shows a third embodiment of the apparatus for isolation of the fibrinogen adhesive. Chambers 30 and
15 31 are connected through the tubing 32, which is regulated by a valve 33. Any suitable type of valve can be used; as shown in FIG. 3, valve 33 operates by sliding the roller so as to pinch off the tubing 32.

Chambers 30 and 31 are attached to each other by
20 sealing or by forming the chambers using the same mold; the chambers are, as before, preloaded with suitable amounts of anticoagulant (chamber 30) and precipitant (chamber 31). Chambers 30 and 31 are provided with outlets 30o and 31o at the sides of the chambers, as
25 shown. Outlet 30o is a Luer lock designed to accommodate a needle as ordinarily attached to a syringe. Outlet 31 is a Luer lock designed to accommodate an externally attached syringe body. Both outlets 30 and 31 have detachable sealing caps 30s and 31s.

30 The chambers 30 and 31 have plungers 30p and 31p which are sealed with gaskets 30g and 31g to the sides of the chambers. When fully withdrawn, the plungers are snug against the end plates 30e and 31e at the bases of the chambers. The plungers are withdrawn by a flexible
35 plastic cord 30c and 31c, which are provided with disks 30d and 31d to aid in the withdrawal. Additional

apertures 30a and 31a permit insertion of rigid rods to push the plungers forward, if required; however, the movement of the plungers is generally effected by application of a vacuum either by withdrawal of the plunger in the adjacent chamber or by an externally attached syringe.

The operation of the apparatus as shown in FIG. 3 is substantially analogous to that shown in FIG. 1. In a typical procedure, the patient's blood, about 60 cc, is withdrawn into chamber 30 with valve 33 and outlet 31b both closed. Outlet 30o is then sealed, the apparatus is placed in a centrifuge, and the plasma and red blood cells in chamber 30 are separated. Valve 33 is then opened and plunger 31p is withdrawn until the red blood cells are seen entering the tubing 32. Valve 33 is closed, and the apparatus is agitated, if necessary, and inverted and centrifuged to separate the fibrinogen adhesives from the supernatant plasma. The red blood cells in chamber 30 may be returned to the patient by an attached needle and pushing the plunger 30p prior to centrifugation, if desired.

After centrifugation, the valve 33 is again opened and plunger 30p withdrawn to draw the supernatant into chamber 30. Withdrawal of the plunger is stopped as soon as the supernatant has left chamber 31.

Outlet 31o is opened and a syringe body attached. The fibrinogen adhesive pellet is disrupted, for example, by repeated motion of the syringe plunger, and, if desired, saline may be included in the attached syringe to achieve quantitative transfer of the fibrinogen adhesive. The adhesive composition is then placed in a suitable applicator for administration to the subject.

Administration and use

The fibrinogen adhesive composition of the invention is useful in medical and veterinary applications generally comparable to those known in the art for the commercially available product Tissucol®. Commercial

preparations of thrombin and calcium ion for admixture with the fibrinogen adhesive of the invention are commercially available and are used as is generally known in the art.

5 In a particularly advantageous way to apply the two components of the sealant to the tissue to be cemented, a dual-barreled applicator with one barrel for supply of the fibrinogen adhesive and the other for the thrombin/calcium ion mixture is employed wherein the
10 outlet of each barrel is proximal to a suction device so that the surface prior to application can be instantly cleaned and excess components immediately removed.

Although the premixing of the components for this purpose is known in the art, as described in U.S.
15 patent 4,359,049, incorporated herein by reference, the advantages of simultaneous application of suction for controlling the environment of the application have not been recognized. To applicants' knowledge, the only medical devices which simultaneously permit application of
20 a material and suction are devices designed for irrigation, such as that described in U.S. patent 4,299,221, where a fluid is applied and then removed from a target tissue, especially in dental applications, for cleansing purposes.

25 In the present application, the provision of suction at the site of sealant application permits the withdrawal of interfering substances as well as control of the quantity of sealant applied. Thus, although the commercially available Duploject device can be used for ap-
30 plication, the modified adhesive applicator described hereinbelow is highly advantageous. This device is designed to permit controlled application of both fibrinogen adhesive and thrombin/calcium mixture with premixing of these components immediately prior to injec-
35 tion along with a means to produce suction for surface cleaning and excess sealant removal.

A particularly advantageous design of such an applicator is shown in FIGS. 4-7 herein, and was described in U.S. Ser. No. 06/683,621 filed 19 December 1984 by the applicant, and now abandoned.

5 In more detail, FIGS. 4 and 5 show a housing 2 which resembles a pen in both size and shape, and which is held in a similar fashion. The interior of the housing 2 includes a chamber 4 having walls that are sufficiently flexible so that the chamber 4 may be compressed by a
10 relatively slight amount of external pressure. At the same time, the walls of the chamber 4 are sufficiently resilient so that, in the absence of external pressure, the chamber 4 will return to its original volume and configuration. The chamber 4 is divided into a first
15 compartment 6 and a separate but identical second compartment 8. In application of the composition of the invention to a subject, one chamber (6) contains the fibrinogen adhesive composition and the other (8) contains the thrombin/ Ca^{+2} preparation. In the preferred embodiment of
20 the present invention, the chamber 4 consists of a rubber bulb, although it is recognized that any chamber whose volume may be easily reduced and expanded may serve as the chamber 4.

The first compartment 6 of the chamber 4 is connected to a first liquid channel 10 which runs lengthwise
25 through the interior of the housing 2 and which terminates at the housing end piece 12. The second compartment 8 of the chamber 4 is likewise connected to a second liquid channel 14 which runs parallel to the first liquid channel
30 91 and which similarly terminates at the housing end piece 92.

The housing end piece 92 is fitted with an adaptor 22 which is configured to receive a connector ~~95~~²⁴ of a
detachable channel extension 25. The channel extension 25
35 includes two liquid channels 26 and 28 (and a suction channel 97 to be described below). When the channel

extension 25 is attached to the housing end piece 92 by means of the adaptor 20 and the connector 23, the liquid channels 28 and 26 serve as extensions, respectively, of the fluid channels 91 and 95 and as reservoirs for the
5 fibrinogen adhesive and the Ca^{+2} /thrombin preparation.

The channel extension 25 may be configured in a variety of lengths and shapes, depending upon the particular requirements of the applicator. The use of a detachable channel extension 25 allows a single applicator
10 housing 2 to be used in conjunction with a variety of differently configured channel extensions 25.

The present invention also includes a mixing head 94 (see FIGS. 6A and 6B). The mixing head 94 includes three entry ports of which two, 34 and 36, are
15 configured to be attached respectively to the distal ends 40 and 42 of the liquid channels 26 and 28.

The interior of the mixing head 94 includes a Y-shaped channel 46 which connects the entry ports 34 and 36 with the exit port 48. The liquid adhesive components
20 dispensed through the entry ports 34 and 36 are thereby combined in the channel 46 before being ejected through the single exit port 48. A single adhesive channel tube 50 is connected to the exit port 48, thus permitting the premixed adhesive to be applied.

25 The apparatus as shown in FIGS. 4 and 5 includes a suction channel 16 which is incorporated into the wall of the housing 2 and which runs parallel to the first and second liquid channels 91 and 95. Suction channel 16 also terminates at the housing end piece 92. The proximal end
30 of the suction channel 16 is surrounded by an adaptor 18 which is configured to connect the suction channel 16 to a remote vacuum source (not shown).

Operation of the suction channel 16 is controlled by means of a venturi opening 96 which is
35 located on the exterior of the housing 2. Obstruction of the venturi opening 96 permits the suction force which

originates at the remote vacuum source to be conducted through the length of the section channel 16.

The interior of the mixing head 94, shown in FIGS. 6A and 6B, also includes a channel 52 which connects the entry port 38 with an exit port 54. The channel 52 serves to conduct the suction force from the distal end 44 of the suction channel 97 to the exit port 54. A single suction channel tube 56 is connected to the exit port 54.

The suction channel tube 56 is shorter than the adhesive channel tube 50 so that the suction channel tube 56 does not interfere visually or functionally with the application of the adhesive. Materials from the site of application, when suctioned, are drawn along the exterior surface of the adhesive channel tube 50 to the orifice of the suction channel tube 56. This provides gentle, atraumatic suction required in microsurgery.

In the apparatus of FIGS. 4 and 5, compression and expansion of the bulb 4 is controlled by means of a leverage mechanism 58. The leverage mechanisms 58 includes an outer lever arm 60 and an inner lever arm 62. Both lever arm 60 and lever arm 62 turn about a fulcrum 64.

The free end 66 of the outer lever arm 60 is positioned adjacent the venturi opening 96 of the suction channel 16. This placement allows the operator to switch rapidly and with a minimum amount of movement from the control of the venturi opening 96 to the control of the lever arm 60.

The free end 68 of the inner lever arm 62 rests against the exterior of the flexible bulb 4. Movement of the free end 68 of the inner lever arm 62 toward the bulb 4 will cause both compartments 6 and 8 of the bulb 4 to be compressed in equal amounts, thereby causing a small quantity of air to be displaced from each of the compartments 6 and 8 through the liquid channels 91 and 95, respectively. Movement of the free end 68 of the inner

lever arm 62 away from the bulb 4 will allow the resilient bulb material to return to its original dimensions.

The lateral motion of the free end 66 of the outer lever arm 60 that is transferred to the free end 68 of the inner lever arm 62 is proportional to the relative lengths of the outer lever arm 60 and inner lever arm 62. If the inner lever arm 62 is shorter than the outer lever arm 60, as shown in FIGS. 4 and 5, then a relatively large lateral motion of the free end 66 will be translated into a relatively short lateral motion of the free end 68. In this manner, a relatively broad finger-controlled lateral movement of the lever arm 60 may be used to control a relatively small displacement of air through each of the liquid channels 91 and 95.

The pivot ends of both the outer lever arm 60 and the inner lever arm 62 are fixed to a ratchet wheel 70. The rotational axis of the ratchet wheel 70 is concentric with the fulcrum 64. Disposed about a portion of the circumference of the ratchet wheel 70 is a set of spaced ratchet teeth 72.

A pawl 74 is positioned to engage the ratchet teeth 72, and to thereby prevent movement of the ratchet wheel 70 in a clockwise direction as shown in FIG. 4. A finger-operable pawl release 76 is attached to the pawl 74. The pawl release 76 provides a mechanism for disengaging the pawl 74 from the ratchet teeth 72, thereby allowing unrestricted movement of the ratchet wheel 70.

The combination of the ratchet wheel 70 and pawl 74 thereby provides a mechanism for stopping movement of the lever arms 60 and 62 (as well as compression or expansion of the bulb 4) at a plurality of fixed intervals. The size of these intervals is dependent on the spacing between the teeth 72 and the circumference of the ratchet wheel 70.

In the apparatus shown, the two components of the dual-component adhesive are drawn into the channels 26 and 28 from a filler tray 78 shown in FIG. 7. The filler tray 78 is designed to orient the operator so that the possibility of drawing a liquid component into the incorrect channel is minimized.

The filler tray 78 is generally of rectangular configuration and divided by a septum 80 along the center of its longer axis into a first container 82 and second container 84. The floor of the first container 82 has a trough 86 which is perpendicular to the septum 80. The floor of the second container 84 has a similar trough 88 which is also perpendicular to the septum 80. Both troughs 86 and 88 are located closer to one end of the filler tray 78 than the other. The resulting asymmetry of the filler tray 78 provides a useful visual orientation for the operator. Both troughs 86 and 88 slant downward toward the septum 80, so that even a small amount of liquid placed in either container 82 or 84 will pool towards the septum 80.

The height and width of the septum 80 are selected so that the distal end 40 of the channel 26 will rest in the lowest part of the trough 88 at the same time that the distal end 42 of the channel 28 will rest in the lowest end of the trough 86. In this way, even small amounts of liquid in the containers 82 and 84 will be directed to the distal ends 40 and 42 of the channels 26 and 28. The height of the septum 80 is selected so that the distal end 44 of the suction channel 97 rests above the septum 80 when fluid is drawn from the filler tray 78. the points at which the distal ends 40 and 42 of the channels 26 and 28 rest adjacent to the septum 80 are the lowest of all points in the filler tray 78. In this way any fluid placed in either container 82 or 84 of the tray 78 will pool towards the distal ends 40 and 42 during the filling of channels 26 and 28.

The filler tray 78 is anchored to a heavyweight base 90 to help prevent the liquid contents of the filler tray from being spilled.

To operate the device, the outer lever arm 60 is first pressed toward the housing 2 so that the fulcrum 64 rotates in a counterclockwise direction as shown in FIG. 4. The free end 68 of the inner lever arm 62 is thereby forced against the exterior of the bulb 4, compressing the bulb. The free end 68 of the lever arm 62 will be held in place against the bulb 4 by means of the pawl 74 engaging the ratchet teeth 72 of the ratchet wheel 70.

The distal ends 40 and 42 of the fluid channels 26 and 28 are then placed into the corresponding containers 82 and 84 of the filler tray 78. The pawl release 76 is operated to disengage the pawl 74 from the ratchet teeth 72. The ratchet wheel 70 is thereby allowed to rotate freely about the fulcrum 64.

In the absence of pressure exerted by the free end 68 of the inner lever arm 62, the resilient flexible material of the bulb 4 will return to its initial configuration, creating a pressure differential between the interior of the bulb 4 and the ambient atmosphere. Atmospheric pressure will force the liquid contents of the filler tray containers 82 and 84 into the corresponding fluid channels 40 and 42 in a volume approximately equal to that of the air originally displaced from the bulb 4.

The distal ends 40 and 42 of the fluid channels 26 and 28 are then removed from the containers 82 and 84 of the filler tray 78. The mixing tip 94 is then attached to the fluid channels 26 and 28 and the suction channel 97. The mixing tip 94 is brought to the work surface. If cleaning of the surface is desired immediately before application of the adhesive, then the venturi opening 96 of the suction channel 16 is closed off by the operator's finger. The suction force created by a remote vacuum attached to the proximal end of the suction channel is

transmitted via suction channel 16 to the work surface. Fluid and debris on the work surface is thereby removed through the suction channel 16.

5 The precise amount of adhesive deposited on the work surface is accurately controlled via the leverage mechanism 58. As the outer lever arm 60 is pressed, the ratchet teeth 72 will rotate past the pawl 74. As each ratchet tooth passes the pawl 74, an audible "click" will be heard.

10 The ratchet teeth 72 may be positioned so that each "click" represents the deposit of a predefined amount of adhesive. For example, if the ratchet teeth 72 are positioned so that each "click" corresponds to the deposit of one microliter of adhesive, then an operator wishing to
15 apply precisely three microliters of adhesive will press the outer lever arm 60 until three "clicks" are heard. The operator's visual attention to the work area thereby remains uninterrupted.

20 At any point during the procedure, application of the adhesive may be halted by merely removing finger pressure from the outer lever arm 60. The lever arm 60 will be maintained in position by the pawl 74 engaging the ratchet teeth 72.

25 In any event, the fibrinogen adhesive of the invention is applied along with a calcium/thrombin composition as understood by the art by any suitable application means.

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